

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s): Dhananjay A. GORE, and Rohit U. NABAR,  
Arogyaswami PAULRAJ and Sumeet SANDHU

Invention: METHOD AND APPARATUS FOR SELECTION AND USE  
OF OPTIMAL ANTENNAS IN WIRELESS SYSTEMS

Antonelli, Terry, Stout & Kraus  
Suite 1800  
1300 North 17th Street  
Arlington, VA 22209

SPECIFICATION

To All Whom It May Concern:

Be it known that we, Dhananjay A. GORE, and Rohit U. NABAR, Arogyaswami PAULRAJ and Sumeet SANDHU, a citizen(s) of India, India, India and United States respectively have invented new and useful improvements in:

of which the following is a specification.

5       METHOD AND APPARATUS FOR SELECTION AND USE OF OPTIMAL  
          ANTENNAS IN WIRELESS SYSTEMS

BACKGROUND OF THE INVENTION

10      The present invention relates to a method and apparatus for transmitting and receiving information across a wireless link using a plurality of antennas. More particularly, the present invention relates to a method and apparatus for selecting an optimal set of antennas from a 15     plurality of antennas for use by a transmitter and/or receiver for improving any performance criterion (such as data rate, error rate, etc) over a wireless link.

20      Current wireless systems generally use single antennas at the transmitter and receiver. For a broad class of wireless systems including mobile and satellite communications, personal communication and wireless network systems, system performance, such as data rate, error rate, etc., can be improved substantially by the use of multiple antennas at the transmitter and/or the receiver.

25      Different approaches and concerns in implementing such multiple antenna systems are, for example, described in "On Limits of Wireless Communications in a Fading Environment When Using Multiple Antennas" by G. J. Foschini et al, Wireless Personal Communications, Kluwer Academic 30     Publishers, vol. 6, No. 3, pages 311-335, March 1998 (Reference 1); "Capacity of Multi-Antenna Array Systems In

5 Indoor Wireless Environment" by C. Chuah et al, Proceedings  
of Globecom '98 Sydney, Australia, IEEE 1998, pages 1894-  
1899 November 1998 (Reference 2); "Fading Correlation and  
Its Effect on the Capacity of Multi-Element Antenna  
Systems" by D. Shiu et al, IEEE Transactions on  
10 Communications vol. 48, No. 3, pages 502-513 March 2000  
(Reference 3); "The Impact of Antenna Diversity On the  
Capacity of Wireless Communication Systems", by J. H.  
Winters et al, IEEE Transactions on Communications, vol.  
42, No. 2/3/4, pages 1740-1751, February 1994 (Reference  
15 4); "Capacity of Multi-Antenna Gaussian Channels" by E.  
Telatar, AT&T-Bell Labs. Internal Technical Memorandum,  
June 1995 (Reference 5); "Increasing capacity in wireless  
broadcast systems using distributed transmission/  
directional reception (DTDR)" U.S. Patent No. 5,345,599.

20 From the references cited above, it is clear that  
multiple antennas at the transmitter and/or receiver can be  
used to increase data rate through spatial multiplexing or  
reducing error-rate through diversity (space-time/space-  
frequency coding) or beam-forming. Future configurations  
25 may move towards striking a balance between these  
techniques. Deployment of multiple antenna technology  
requires the development of advanced space-time/space-  
frequency processing at the transmitter and receiver. Our  
invention while facilitating the use of multiple-antenna  
30 technology is not restricted to any particular space-  
time/space-frequency processing at the transmitter and/or

5 receiver but is generally applicable to any wireless transmission/reception scheme employing a plurality of antennas at the transmitter and/or receiver. The particular transmission/reception scheme used will impact the implementation of this invention and vice versa.

10 Although increasing the number of antennas for transmitting and/or receiving in a wireless system improves the performance of a wireless link, there are some limitations on the applicability of such a strategy. Namely, in such systems for every transmit antenna and  
15 every receive antenna a separate RF chain must be provided. Thus, as the number of antennas at transmitter or receiver increase so do the number of RF chains required.

20 RF (Radio-frequency) chains (transmitter RF chains in particular) are much more expensive than the antenna elements. Thus, increasing the number of antennas in such systems would in effect increase the cost of the system.

Therefore, there is a need to provide a technique that takes advantage of the benefits provided by the use of  
25 a multiple antenna configuration without unnecessarily increasing the cost of the apparatus. In addition, under certain circumstances, system performance can be improved by using fewer RF chains than antennas available. The key idea of this patent, namely selection of an optimal set of  
30 antennas from a plurality of available antennas at the

5 transmitter and/or receiver to connect the RF chains to is  
equally applicable in both cases.

Existing patents in related areas include "Receive antenna selection method and diversity receiver ", US Patent #6141392, "Impairment determination for a diversity antenna selection process ", US Patent #6118773, "Diversity antenna selection ", US Patent #6002672 and "Method and arrangement for antenna selection control in a radio receiver ", US Patent #5991613. All of the above patents are concerned with only single antenna selection at either the transmitter or receiver. None of them refer to multiple antenna selection and are concerned mostly with improving diversity in the system. Our invention deals with the selection of multiple sets of antennas at the transmitter and/or receiver for any criterion such as spatial multiplexing, beam-forming, diversity etc. Our invention is novel and sufficiently different from those mentioned above.

#### SUMMARY OF THE INVENTION

25 The present invention provides a method and apparatus wherein a relatively smaller number of RF chains are used at the transmitter and/or receiver and wherein an optimal set of antennas to be used by the RF chains is selected from a plurality of antennas for use in transmitting and/or receiving a wireless signal on a wireless link.

5 According to the present invention a plurality of  
RF chains and a plurality of antennas are provided at the  
transmitter and/or receiver and the number of RF chains is  
smaller than or equal to the number of antennas. Further,  
according to the present invention, information concerning  
10 transmission and reception of wireless signals on a  
wireless link is determined and an optimal set of antennas  
from the plurality of antennas is selected based on the  
information at the transmitter and/or receiver. The RF  
chains are then connected to the optimal set of antennas to  
15 permit transmission or reception of wireless signals on the  
wireless link via the optimal set of antennas.

According to the present invention it might be  
advantageous economically (or from the perspective of  
improved performance) to use a small number of RF chains  
20 and a large number of antennas and connect the RF chains to  
a selected set of optimal antennas that provide the best  
performance of the wireless link. One of the basic goals  
of selecting the optimal set of antennas is to optimize the  
wireless link being used according to a predetermined  
25 criterion including any one of capacity, diversity, spatial  
multiplexing or any other criteria for which the wireless  
link is to be used.

5 BRIEF DESCRIPTION OF THE DRAWINGS

The scope of the present invention will be apparent from the following detailed description, when taken in conjunction with the accompanying drawings, and such detailed description and specific examples, while 10 indicating example embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description in which:

15 Fig. 1 is a schematic diagram of an example of apparatus configured according to the present invention; and

20 Fig. 2 is a flowchart of the steps performed according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will be described with respect to Figs. 1 and 2. However, it should be noted that the present configuration as illustrated in Figs. 1 and 2 25 is representative of an embodiment of the present invention. The present invention is not limited to the embodiment illustrated herein. The present invention can be implemented according to any number of embodiments with the primary feature being the selection of an optimal set 30 of antennas from a plurality of antennas wherein the optimal set of antennas corresponds to the number of

5 transmit and/or receive RF chains having a number less than  
or equal to the number of antennas.

The present invention is intended to operate in a wireless system with multiple antennas at the transmitter and/or receiver. Particularly, the invention provides a  
10 method and apparatus for use in a system having a plurality of antennas for transmitting and/or receiving wireless signals over a wireless link. According to the present invention, a plurality of RF chains are provided having a number smaller than or equal to that of the plurality of  
15 antennas. Information concerning transmission or reception of wireless signals on the wireless link is determined and an optimal set of antennas from the plurality of antennas is selected based on the information. The optimal set of antennas is connected to the RF chains to permit  
20 transmission or reception of wireless signals from or to the RF chains on the wireless link via the optimal set of antennas. According to the present invention, the information is used so as to select the optimal set of antennas that optimizes the wireless link according to  
25 criteria including any one of capacity, diversity, spatial multiplexing or any other criteria for which the wireless link is to be optimized.

A discussion of a proof of the benefits of implementing the invention in multiple antenna systems in  
30 the special case of improving capacity and the processing necessary so as to select the optimal set of antennas at

5 the transmitter for particular channel conditions can be  
found in "Selection and Use of Optimal Transmit Antennas in  
Wireless Systems", ICT'2000, Acapulco, Mexico, May 2000 by  
R.Nabar. D.Gore and A.Paulraj; "Selecting an Optimal Set of  
Transmit Antennas for a Low Rank Matrix Channel",  
10 ICASSP'2000, Istanbul, Turkey, June 2000 by D.Gore, R.Nabar  
and A.Paulraj; "A Near-Optimal Technique for Selecting  
Transmit Antennas based on Shannon Capacity", Asilomar  
CSSC, Asilomar, Nov.2000 by S.Sandhu, R.Nabar, D.Gore and  
A.Paulraj. Though the above papers refer to the case of  
15 antenna selection at the transmitter for maximizing  
capacity, the invention is applicable to any other  
criterion with selection of an optimal set of antennas from  
a plurality of antennas at the transmitter and/or receiver.

The features of the present invention can be  
20 applied to a multiple antenna system such as that of the  
MEA or MIMO type systems. One such configuration of the  
invention is illustrated in Fig. 1.

The present invention as illustrated in Fig. 1  
provides a transmitter 30 that transmits wireless signals  
25 31 via transmit antennas 302 on a wireless link to a  
receiver 32. The transmitter 30 consists of a space-time  
processing unit 304 that converts the data to be  
transmitted into signals to be transmitted from each of the  
antennas 302. The receiver 32 receives such wireless  
30 signals 31 via receive antennas 321, and using detected  
information concerning the wireless signals, determines

5 information concerning transmission of the signals on the wireless link. Based on such information an optimal set of antennas 302 that should be used to transmit the wireless signals 31 to the receiver 32 and an optimal set of receive antennas 321 to receive the signals 31 is determined. Such  
10 information is provided to the transmitter, for example, through a feedback path 33 from the receiver 32 to the transmitter 30. The receiver 32 also consists of a space-time processing unit 324 to convert the signals received on the antennas 321 into output data.

15 The transmitter 30 includes a plurality of RF chains 301-1 through 301-k which can be selectively coupled to a plurality of antennas 302-1 through 302-n by a switch 303. The switch 303 can connect k RF chains 301 to any set of k transmit antennas from the n available transmit  
20 antennas 302. The receiver 32 includes a plurality of antennas 321-1 through 321-m which can be selectively coupled to a plurality of RF chains 323-1 through 323-w by a switch 322. The switch 322 can connect w RF chains 323 to any set of w receive antennas from the m available  
25 receive antennas 321.

According to the present invention the number of RF chains 301 is less than the total number of transmit antennas n available for use by the transmitter 30. Also, the number of RF chains 323 at the receiver is less than 30 the total number of receive antennas m available for use by the receiver 32. The switch 303 responds to the information

5 provided by the feedback path 33 from the receiver 32 so as  
to cause the switch 303 to connect k RF chains 301 to the  
optimal set of transmit antennas 302. Similarly, the switch  
at the receiver 322 connects the w RF chains 323 to the  
optimal set of w receive antennas 321.

10 The receiver includes an optimal set computation  
unit 320 which based upon the wireless signals 31  
transmitted on the wireless link, determines information  
which is used to select an optimal set of transmit antennas  
302 and receive antennas 321 which should be used to  
15 transmit and receive wireless signals from the transmitter  
30 and receiver 32 respectively. Therefore, the optimal set  
of antennas is chosen according to the information  
concerning the wireless link upon which the transmissions  
are to occur so as to optimize performance over the  
20 wireless link. This information concerning the wireless  
link is gathered and/or detected by the optimal set  
computation unit 320 and used to compute the optimal set of  
transmit antennas 302 and receive antennas 321 to conduct  
the transmission and reception on the wireless link.  
25 Information concerning the transmit antennas 302 to be  
selected is provided by the feedback path 33 to the  
transmitter from the optimal set computation unit 320.

According to the invention, the information  
concerning the wireless link gathered and/or detected by  
30 the optimal set computation unit 320 is used to optimize  
the wireless link according to criteria including any one

5 of capacity, diversity, spatial multiplexing or any other  
criteria for which the wireless link is to be used. It  
should be noted that the optimal antenna set can be  
computed at the transmitter 30 itself if the channel is  
known to the transmitter 30 (as in the case of TDD (Time  
10 Division Duplex) systems) or if the channel state is fed  
back to the transmitter 30.

The procedure performed by the above-described  
apparatus for implementing the present invention is  
illustrated by the flowchart of Fig. 2. It should be noted  
15 that each of the steps of the flowchart could, for example,  
be instructions or sections of code of a computer program  
that could, for example, be executed by the optimal set  
computation unit 320.

According to the flowchart illustrated in Fig. 2,  
20 the invention offers a selection of n transmit antennas 302  
for coupling to k RF chains 301 (step 401) and m receive  
antennas 321 for coupling to w RF chains 323. Thereafter,  
the selection criterion is determined (step 402). The  
criterion can be any one of capacity, diversity, spatial  
25 multiplexing or any other criteria that could be used to  
optimize the wireless link upon which wireless signals are  
transmitted between the transmitter and the receiver.

After determining the selection criterion, an  
estimate is performed of the matrix channel,  $H(m \times n)$  and an  
30 update time c (time chosen by system designers to update  
channel state information) (step 403). This step can be

5 performed at either the transmitter 30 or the receiver 32  
depending on the system. The timer is then set to 0 (step  
404). Thereafter, the best set of k transmit antennas 302  
and w receive antennas 321 is determined based upon the  
selection criteria determined according to step 402 (step  
10 405). The basic intent here is to optimize some system  
parameter such as data rate, bit error rate, etc so to  
optimize use of the wireless link upon which wireless  
signals are transmitted between the transmitter 30 and the  
receiver 32.

15 Once the best set of k transmit antennas 302 and  
w receive antennas 321 has been determined, the k RF chains  
301 are then connected through a switch 303 to the selected  
set of k transmit antennas 302 (step 406) and the w RF  
chains 323 are connected through a switch 322 to the  
20 selected set of w receive antennas 321. A step is  
performed so as to determine whether the time elapsed is  
greater than the update time c. If the time set by the  
timer is greater than the update c time then the procedure  
moves back to step 403. Otherwise the system continues to  
25 monitor the timer and waits until the timer exceeds the  
update time c before proceeding to step 403.

Thus, by use of the invention as, for example,  
illustrated in Fig. 1, an optimal set of transmit antennas  
302 are switched so as to be coupled to the fixed number of  
30 RF chains 301 based upon information concerning the  
selected optimal set of transmit antennas 302 provided by

5 the computation unit 320 along the feedback path 33. The  
information provided by the computation unit 320 also  
enables coupling the optimal set of receive antennas 321 to  
the fixed number of RF chains 323 at the receiver.

It should be noted that the optimal set  
10 computation unit 320 could also, for example, be positioned  
in the transmitter 30 thereby eliminating the feedback path  
33 from the receiver 32 to the transmitter 30. Further, it  
should be noted that the feedback path 33 could, for  
example, be provided through a wireless communications  
15 network (not shown) within which the transmitter 30 and  
receiver 32 are used. Additionally, it should be noted that  
that the choice of transmit antennas 302 and receive  
antennas 321 made by the computational 320 unit may not be  
optimal, but sub-optimal or close to optimal due to  
20 limitations of complexity or other design criteria.

Further, it should be noted that a similar  
configuration and selection apparatus could be created  
under the framework of this invention to select an optimal  
set of antennas from a plurality of receive antennas 321 at  
25 only the receiver 32 or an optimal set of transmit antennas  
from a plurality of antennas 302 at only the transmitter.

While the present invention has been described in  
detail and pictorially in the accompanying drawings it is  
not limited to such details since many changes and  
30 modifications recognizable to those of ordinary skill in

5 the art may be made to the invention without departing from  
the spirit and the scope thereof.